CORRELATION-TYPE ULTRASONIC WATER METER DRK-M

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This article examines a method of measurement used in a correlation-type water meter in which the signals are picked up ultrasonically.

The correlation method of measuring flow rate is based on determination of the velocity of a liquid flow from markers moving at the same velocity as the flow and the subsequent analysis of two random signals. In contrast to the eddy method, the correlation method does not require the introduction of a foreign object into the flow. Thus, there is also no additional pressure gradient.

The markers used to calculate the velocity of water (and, thus, to also calculate flow rate) are natural eddies in the flow. These eddies are steady in character at flow velocities above 0.4 m/sec.

The turbulent processes associated with the eddies are not periodic and deterministic but are instead random in nature. The initial quantity used to calculate the velocity of the water in a pipe is the time it takes a steady-state random process to travel between two cross sections of the pipe located a known distance from one another. This lag time is also called the transport lag time or correlation time.

Conventional methods of measuring time lags cannot be used to measure the lag time of two random signals that are functions of the eddies in a flow (for example, to measure the time parameters of single pulses) because the signals are random in form and aperiodic. Such measurements are made by using the correlation method for the analysis of random signals. This method entails calculation of the correlation function $R_{xy}$:

$$R_{xy}(\tau) = \lim_{T \to \infty} \frac{1}{T} \int_0^T X(t-\tau) Y(t) dt,$$

where $\tau$ is the correlation time; $T$ is the period of measurement; $X(t)$ and $Y(t)$ are two random signals being examined.

The value of the function $R_{xy}$ at the point $T_1$ determines the degree of correlation (coupling, similarity, identity when superimposed) of two signals when one lags behind the other by the amount $\tau$. The maximum of the correlation function $R_{xy}$ indicates the magnitude of the lag at which the best agreement will be obtained. That magnitude will also be the average value when one of the turbulence points passes through two successive cross sections of the pipe (similar to the manner in which the two recorded oscillograms are shifted relative to one another until they reach the position at which the best agreement is obtained).

The ultrasonic correlation method is realized in flowmeter DRK-M. In order to obtain information on the passage of eddies through two cross sections of a pipe, four acoustic transducers (two emitters and two detectors) are included in the primary sensor of the DRK-M. The transducers are mounted on the pipe in accordance with the "Technical Description of the DRK-M and Operating Instructions." The transducers are mounted so that the two ultrasonic beams from the emitters are parallel and are positioned a certain distance from one another. This distance (roughly equal to the diameter) is calculated with allowance for the exact internal diameter of the pipe. The chosen distance $L$ is one of the main geometric parameters of the primary sensor.

A turbulence point undergoes a change in phase and amplitude when it intersects one of the ultrasonic beams. In contrast to ultrasonic flowmeters that measure the difference between the time of passage of acoustic vibrations along the flow and counter to the flow, in correlation-type ultrasonic flowmeters the absolute values of the time lags, the fact that they change

slowly over time, and the difference in the absolute values of the lags between two channels are unimportant. The useful information is conveyed by the relative change in the phase of the high-frequency signal at the output of the ultrasonic detector.

First of all, this situation makes it possible to set up the measurement system with the use of any radio-frequency cable (the length of the cable is chosen on site). Secondly, it makes it possible to limit the metrological certification (testing) of the primary sensor to documentation of the geometry of the assembled system and a simple check of the functioning of the sensors with respect to the presence of signals from the detectors (which travel over the XS3 and XS5 cable connections of the DRK-M). The certification is done in accordance with the guidelines in "Method of Testing the Transducers of Ultrasonic Correlation Flowmeter DRK-M."

The signals obtained from the primary sensor are analyzed in the electronic converter (secondary sensor) of the DRK-M. High-frequency signals travel to the converter of the DRK-M from the ultrasonic detectors, these signals having been modulated in phase and amplitude by the eddies in the flow. The signals are demodulated in phase, giving two low-frequency envelopes. One of the envelopes lags in time behind the other envelope. The analog envelopes are then converted into digital signals and sent to the inputs of the computer that calculates the correlation function.

The DRK-M employs an algorithm that is continuous in time. The algorithm calculates the correlation function, gradually generates a new value, and stores the different values of the function. The algorithm was specially designed to calculate the coordinates of the peak of the function in running (real) time. Thus, such a parameter as the time of integration T does not enter explicitly into the conversion function that is used.

The continuous algorithm is realized as follows. At the beginning of operation of the system, the correlation function is constructed as a result of the accumulation of signal matches X(t−τ) and Y(t) in the corresponding cells of a digital filter N. Here, the greater the value of the correlation function at point N, the more rapidly such matches are accumulated in the corresponding cell. When the highest cumulative number in one of the cells reaches the level at which the digital comparator (a DRK-M—240 comparator, for most applications) is activated, the number of that cell is recorded in the buffer register. This value N is used as the coordinate of the maximum of the correlation function and is converted into output signals (current, period, response time of the mechanical counter). After activation of the comparator, the digital filter changes over to the mode of operation in which nonmatches are subtracted. In this mode, the greater the value of the correlation function at a point, the more slowly the contents of the corresponding cell of the filter will "settle down."

The technical characteristics of the DRK-M flowmeter allow it to be used to measure the rate of flow and volume of water (drinking, industrial, and river water, sewage, water in water-management systems, heating systems, and water-supply systems). The measurement must be performed in completely closed pipes (penstocks). Since the value of flow rate is calculated by the computer of the flowmeter on the basis of mean flow velocity, an additional error will be created if one section of the pipe is only partly filled. This error will be equal to the relative size of the unfilled part of the pipe cross section.

The DRK-M flowmeter (Certificate No. 1221, indicating the type of instrument entered in the State Register for Measuring Instruments under the number 14259—94) is a modification of flowmeter DRK (No. 13368-92 in the State Register) and has improved metrological characteristics. In particular, the meter can be used on pipes ranging in diameter from 43 to 4200 mm, the minimum flow rate that can be measured (in a 50-mm-diam. pipe) is 2.88 m³/h, and the error of measurement of volume and flow rate is 1.5%.

The largest value of the ratio of the maximum measurement limit to the minimum limit is 10. The length of the straight sections of the pipe should be at least five diameters (at least 10 diameters after pumps and valves).

The temperature of the liquid measured in the DRK-M can range from 1 to 150°C. The pressure of the liquid can range up to 2.4 MPa (24 atm).

The mechanical volume meter is a six-digit meter.

In accordance with the "Technical Description and Operating Instructions," the primary sensor of the DRK-M can be mounted on existing pipes by using the straight sections of the pipes as the measurement sections. This feature is very important for pipes of large diameters. The mounting is done by welding four lugs onto the wall of the pipe and then inserting the primary sensors into the lugs.

In the correlation method, the two ultrasonic beams are perpendicular to the axis of the pipe and the flow of water is "scanned" by the beams over the diameter (this is in contrast to the other two ultrasonic methods, in which a longitudinal section of the pipe is "scanned" over a diagonal in both directions). The ultrasonic beams in the DRK-M are continuous, harmonic, and independent of one another. This makes it possible to connect the secondary sensor to the primary sensor by any type of high-frequency cable (with a length up to 300 m), which in turn allows the signal to be transmitted at a frequency of 1 MHz. No special requirements need be satisfied in regard to the phase-frequency matching of the cables. On the one hand,